[redacted]A GRANT PUBLICATION 46

PERFORMANCE OF TETHERED FLOAT BREAKWATERS IN DEEP OCEAN WAVES

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UNIVERSITY OF CALIFORNIA
SEA GRANT COLLEGE PROGRAM

IMR REFERENCE 76–4

INSTITUTE OF MARINE RESOURCES
MAIL CODE A-032
UNIVERSITY OF CALIFORNIA
LA JOLLA, CALIFORNIA 92093

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Sea Grant Publication No. 46

January 1976

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La Jolla, California 92093

Approved for distribution:

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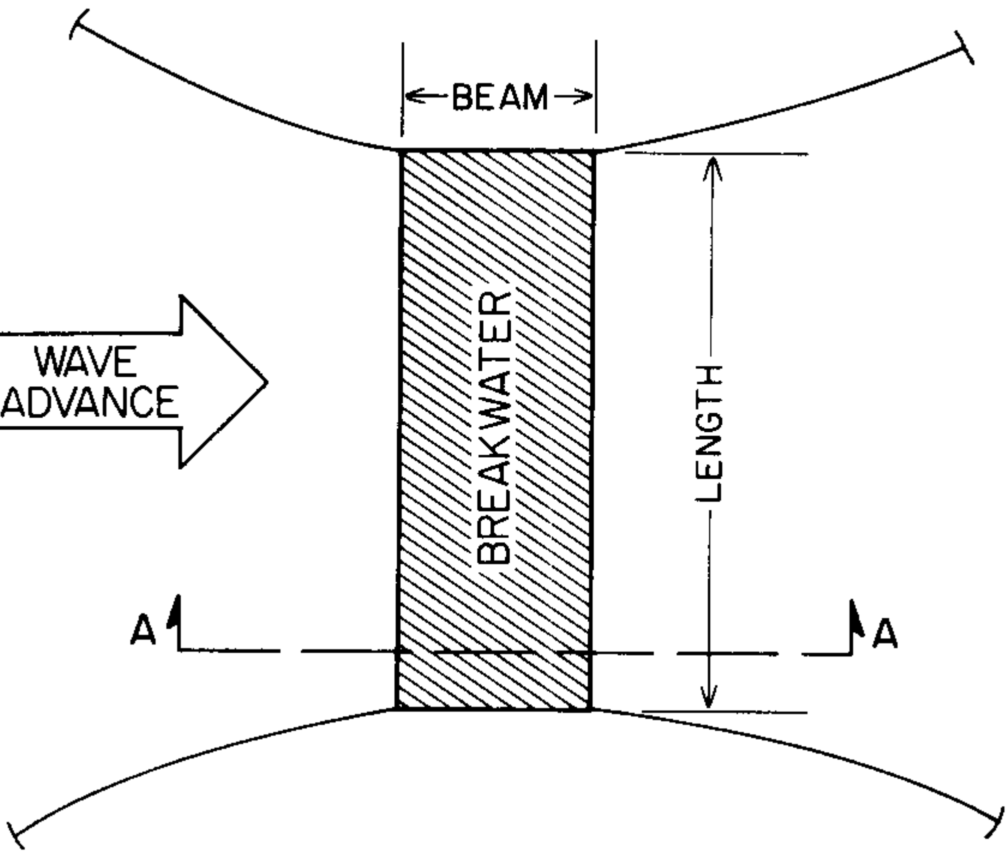
1. INTRODUCTION:

The tethered float breakwater, as depicted in Figure 1, can be defined in functional terms by specifying the float diameter and density, the float spacing in the length direction, the tether length, the number of rows in the beam direction, and the water depth.

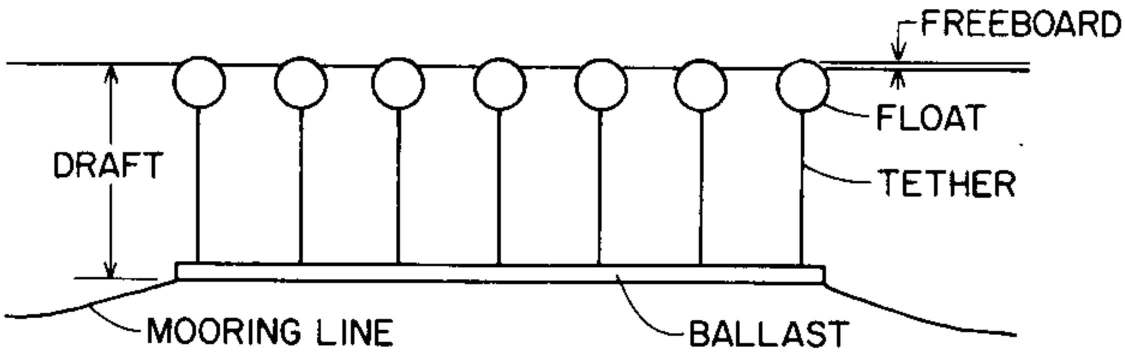
The performance of this system, following the recommendations of Kowalski (1974), is given by a height transmission coefficient, C_t, which is the ratio of the transmitted and incident significant wave heights. In practice, this ratio is approximated for broad spectra by taking the ratio of the standard deviations of the transmitted and incident wave heights.

Seymour and Isaacs (1974) describes a method for predicting the performance of a tethered float breakwater of arbitrary design for any given wave climate. This predictive model has been shown to approximate very closely the performance of laboratory scale breakwaters and of functional systems for limited fetch applications as described in Essoglou et al (1975).

This report describes the results of employing the predictive model to investigate performance in deep water with ocean waves. Performance in shallow water will be the subject of a separate report.



PLAN VIEW



SECTION A-A

DEFINITION SKETCH – TETHERED FLOAT BREAKWATER

FIGURE 1

2. WAVE ENVIRONMENT:

To simplify discussion, two types of incident wave spectra will be referred to in this report. The first will be the standard spectrum based upon the model proposed by Pierson and Moskowitz (1964). The spectrum will be identified by the deepwater wave length appropriate to the period of peak energy to facilitate scaling. The wind speed, which is the normal parameter to identify the Pierson-Moskowitz spectrum, is related to the peak wavelength and the peak period by

$$V_k = 6.89\ (\lambda_\circ/g)1/2 \tag{1}$$

and

$$\lambda_\circ = g/_{2\pi}\ T_p^{\ 2} \tag{2}$$

where V_k = wind speed, knots

$\lambda_\circ$ = deepwater wavelength corresponding to peak energy period

g = gravitational constant

T_p = period of peak energy

The significant wave height for this spectrum is given by

$$Hs = 0.0237\ \lambda_\circ \tag{3}$$

The second type of spectrum, referred to as the modified spectrum, is the typical bimodal swell and sea combination prevalent in many parts of the world. This spectrum is approximated here by adding two single peak spectra of the type described above. It will be assumed arbitrarily here that the longer wavelength swell will be decayed to 1/3 of its fully developed significant wave height. The shorter wavelength sea component will be fully developed and have a peak wavelength equal to 0.25 $\lambda_\circ$. This means that the sea component peak period will be half that of the swell component. For example, a spectrum defined by $\lambda_\circ$ = 189 m. refers to an 11 second peak period swell spectrum with energy decayed by 89% from its fully developed state summed with a 5.5 second peak period fully developed sea.

The significant wave height of this modified spectrum is given by

$$H_{s_{MOD}} = 0.00984\ \lambda_\circ \tag{4}$$

The water depth will be assumed to be 100 m. so that the depth effects on wave parameters can be safely ignored. The standard and the modified spectra for V_k = 30 kts, $\lambda_\circ$ = 216 m., T_p = 11.8 sec. are illustrated in Figure 2.

3. BREAKWATER SCALING:

The various breakwater design parameters, such as float diameter and tether length will be defined non-dimensionally by normalizing each length dimension with the peak wavelength, $\lambda_\circ$. The following symbols will be employed to describe dimensionless lengths:

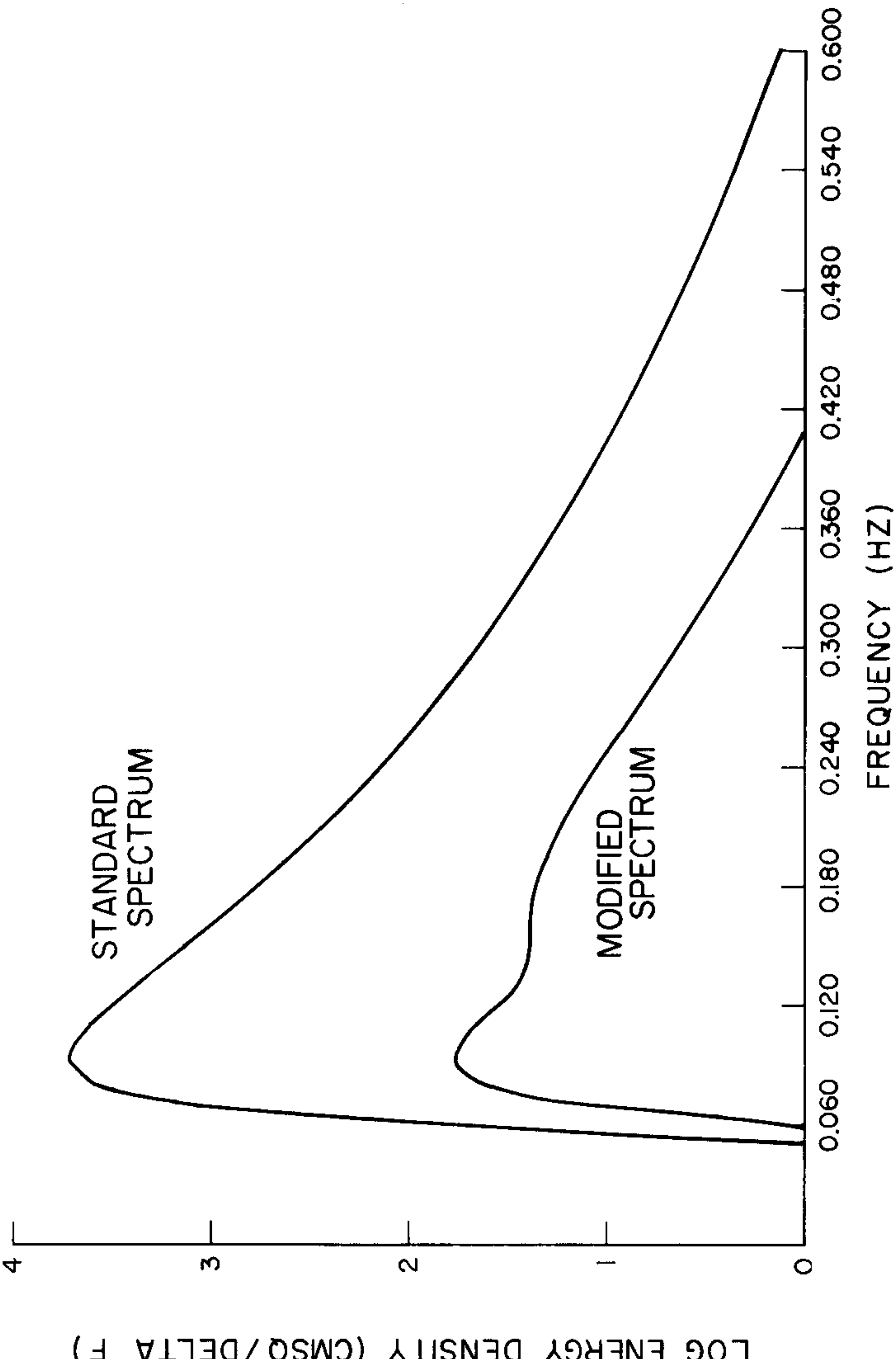
d^* = float diameter/$\lambda_\circ$

L^* = effective tether length/$\lambda_\circ$

b^* = beam width /$\lambda_\circ$

In all designs, it is assumed that 20% of the floats have a freeboard (see Figure 7) of one half diameter to provide reserve buoyancy. All other floats have a negative freeboard of one quarter diameter.

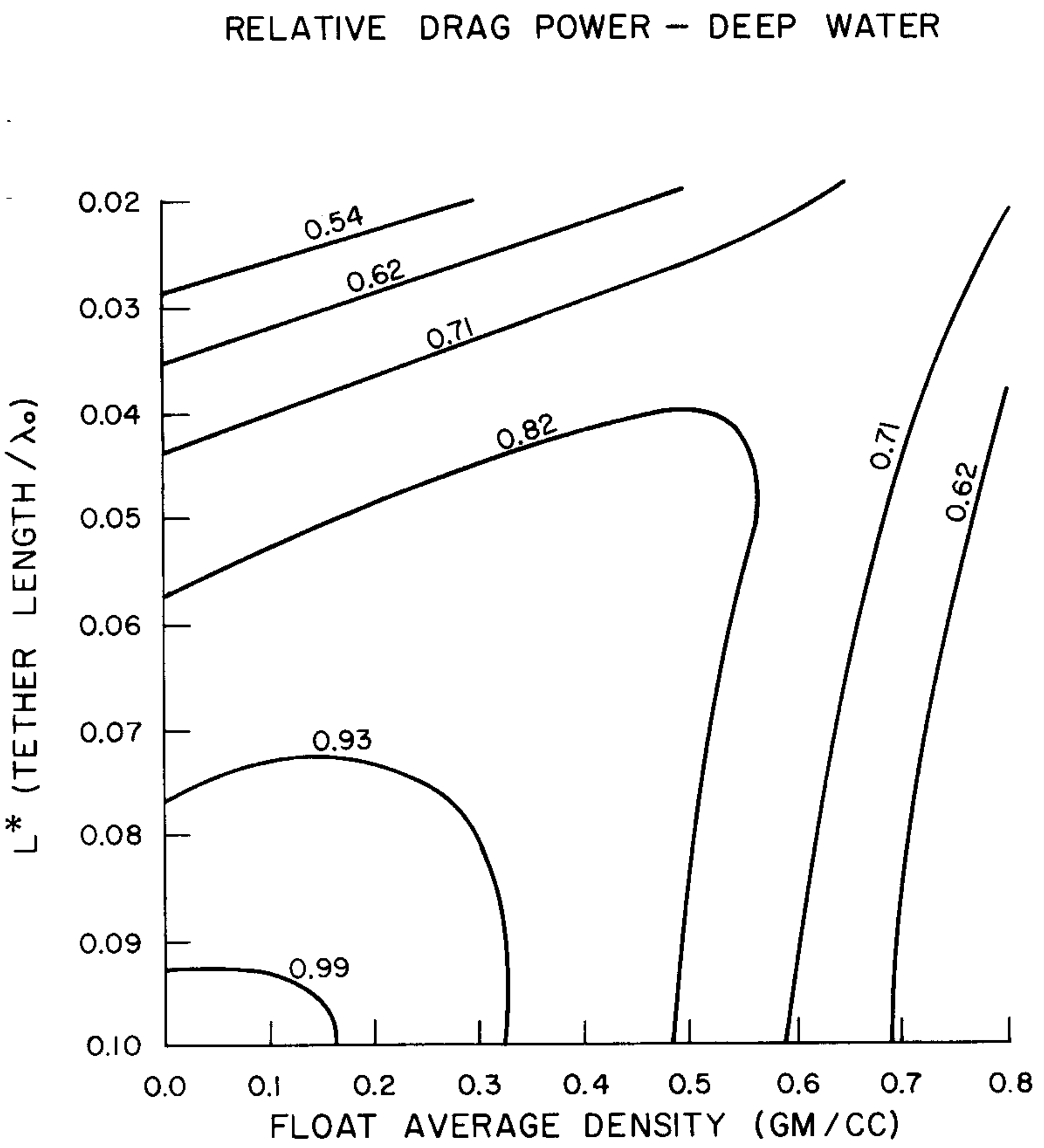
Figure 2


STANDARD
SPECTRUM
MODIFIED
SPECTRUM
FREQUENCY (HZ)
LOG ENERGY DENSITY (CMSQ/DELTA F)
0.060
0.120
0.180
0.240
0.300
0.360
0.420
0.480
0.540
0.600
0
1
2
3
4

4. EFFECTS OF ALTERING DESIGN VARIABLES:

Figure 3 shows contours of relative float drag power for various non-dimensionalized tether lengths and various float densities. Since the wave energy attenuation rate is proportional to the drag power, these curves yield a qualitative estimate of the performance changes associated with variations in these parameters. The optimum tether length for the lowest float density is approximately 0.098, or about 10% of the deepwater wave length for the period of peak energy. This curve was plotted for a float diameter $d^* = 0.00423$. The value of the optimum tether length decreases very slightly for smaller float diameters and increases very slightly for larger floats. However, for low density floats and sharply peaked spectra (of the form of the standard spectrum), 10% of λ_o is a useful approximation for any diameter. With more dense floats, as indicated in Figure 3, the optimum tether length decreases slightly. It can also be seen that the lowest float density yields the highest performance. An average float density of 0.04 gm/cc (2.5 lbs/cu.ft.) appears to be approximately the minimum attainable construction for ocean scale floats. An increase in diameter and mass caused by fouling organisms causes a net degradation of the performance of deep water systems as described in Seymour and Hanes (1975). Since deep water operation poses no limits on tether length, it is assumed that the tethers will always be optimum for the design con-

Figure 3


RELATIVE DRAG POWER — DEEP WATER
0.54
0.62
0.71
0.82
0.93
0.99
0.71
0.62
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
L* (TETHER LENGTH / λo)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
FLOAT AVERAGE DENSITY (GM / CC)

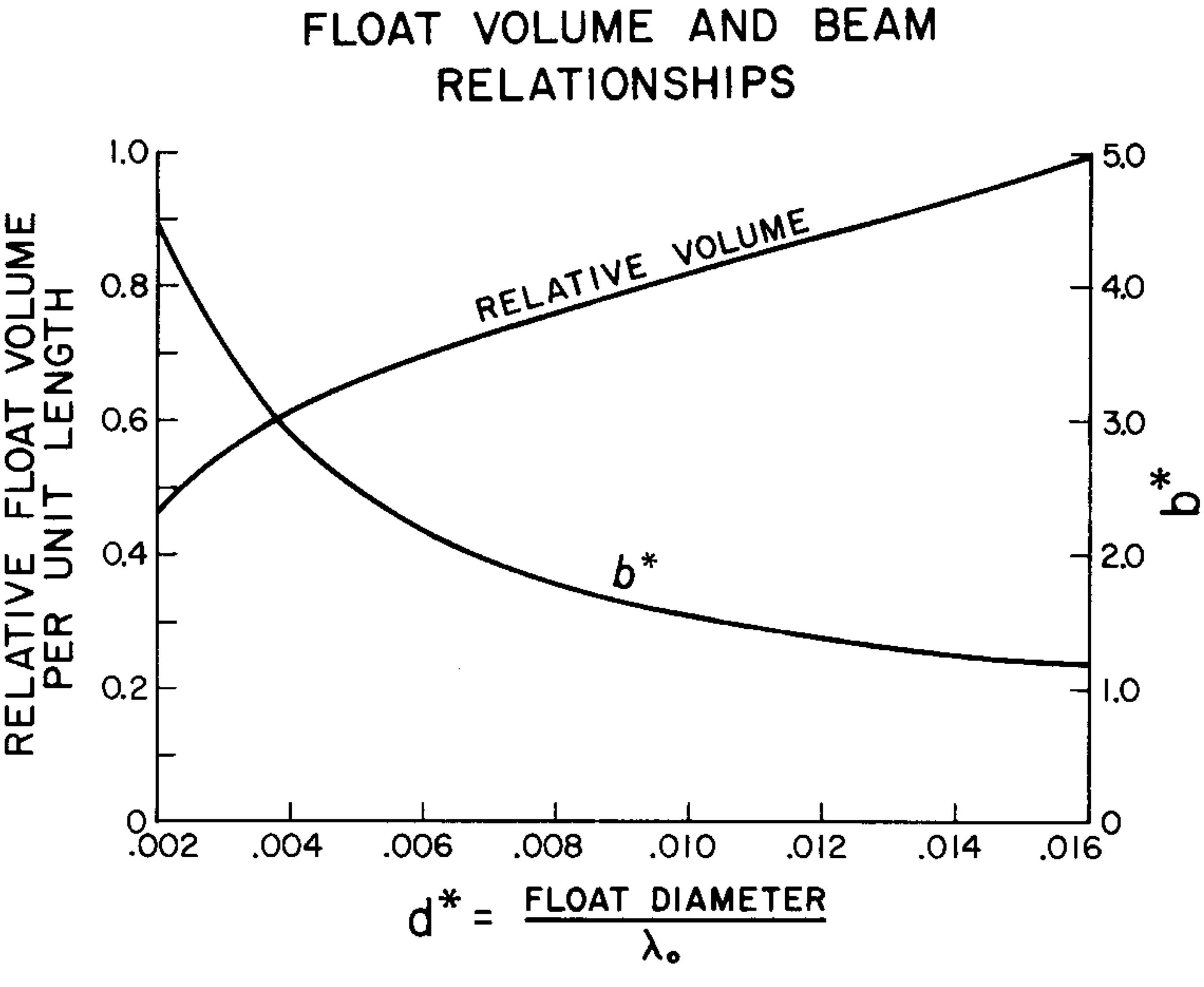
dition. The further assumption that only low density floats will be employed (approximately 0.04 gm/cc) allows the float diameter to be treated as the single variable in the system.

5. EFFECTS OF FLOAT DIAMETER ON SYSTEM PERFORMANCE:

The wave attenuation performance is normally defined in terms of C_t and the incident wave spectrum. For present purposes, C_t will be arbitrarily set at 0.5. To allow an assessment of the economic impact of float diameter selection, the breakwater design will first be described in terms of the relative volume of floats required per unit length of breakwater to achieve the 50% height reduction. Since ballast cost, float cost and - to some extent - tether cost are closely related to float volume, this methodology provides a simplified means of evaluating total breakwater cost trends.
Figure 4 shows the relative float volumes for a range of non-dimensional float diameters from 0.002 to 0.016 at L* = 0.098 and float density = 0.04 gm/cc.
Also plotted on the same figure is the non-dimensional beam, b*, for the same diameter range. Both curves are based upon a spacing between floats of two diameters, center to center, in both the beam and length directions.

Figure 4 shows that the required float volume increases rapidly with increased diameter but that the beam dimension increases rapidly with decreasing diameter.

Figure 4


FLOAT VOLUME AND BEAM RELATIONSHIPS
RELATIVE FLOAT VOLUME PER UNIT LENGTH
1.0
0.8
0.6
0.4
0.2
0
5.0
4.0
3.0
2.0
1.0
0
b*
RELATIVE VOLUME
b*
.002
.004
.006
.008
.010
.012
.014
.016
d* = FLOAT DIAMETER / λ₀

6. EFFECTS OF SPECTRAL WIDTH ON SYSTEM PERFORMANCE:

The breakwater attenuates wave energy more efficiently with a broad band incident spectrum, as typified by the modified spectrum of this report, than it does with a narrow, more sharply peaked spectrum like the standard Pierson-Moskowitz form. This is illustrated in Figure 5, where the number of rows to achieve C_t = 0.5 for various values of d* are shown for each type of spectrum. The number of rows for the modified spectrum can be seen to be always considerably less than the number required for the standard spectrum. Comparing the two spectra in Figure 2, it is obvious that the standard spectrum contains several times the energy of the modified spectrum and it would be logical to assume that the difference in the number of rows required is related to energy content rather than to spectral width. However, the performance is remarkably independent of the energy level for a given spectral shape and peak period. Table I shows the comparison in numbers of rows required for d* = 0.01 with the standard spectrum and with the same spectrum multiplied by a constant factor such that its significant wave height is reduced to that of the modified spectrum. Since the required number of rows increases slightly with large decreases in wave energy, it can be seen that it is spectral shape rather than energy content which designs the system.

Figure 5

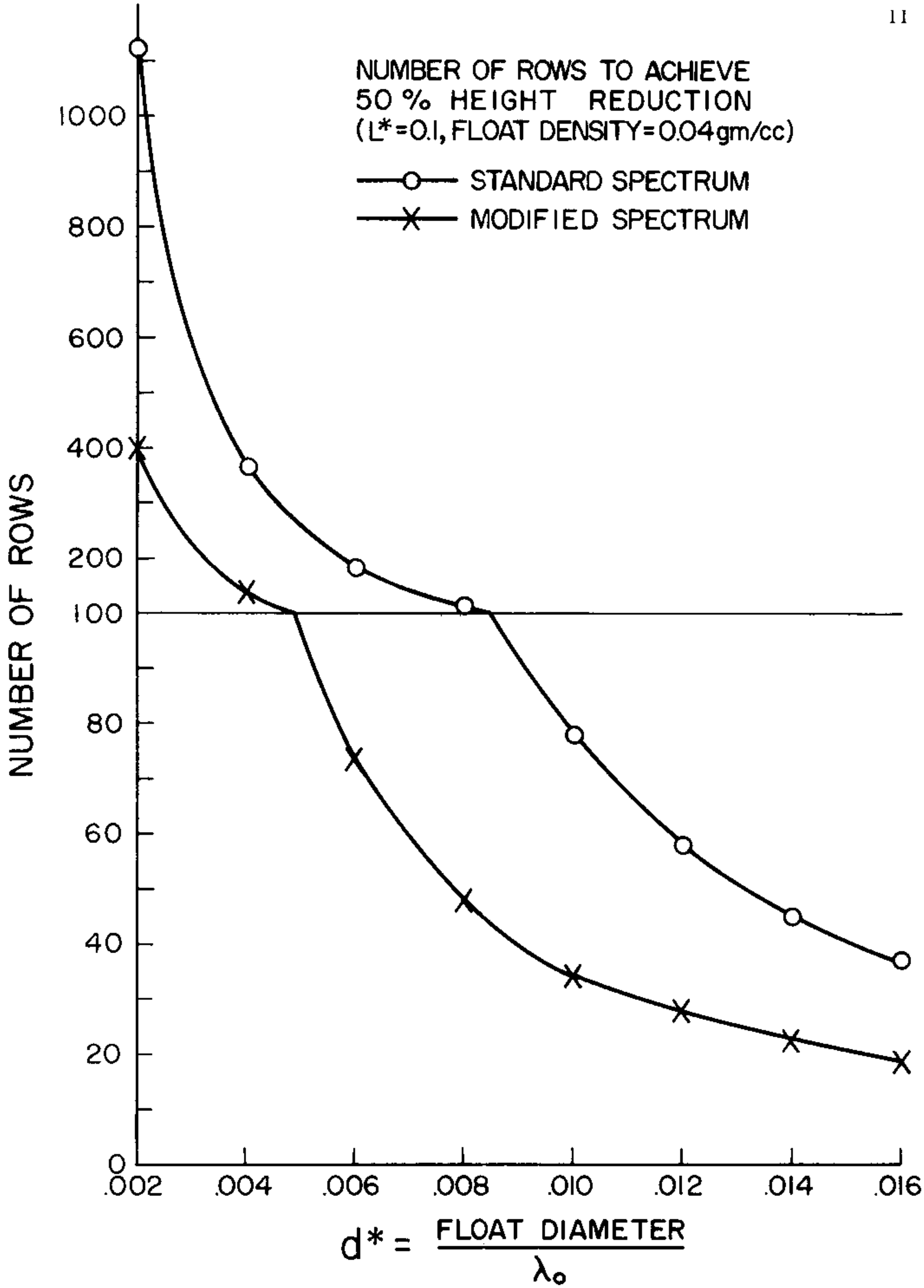

NUMBER OF ROWS TO ACHIEVE
50 % HEIGHT REDUCTION
(L* = 0.1, FLOAT DENSITY = 0.04 gm/cc)
STANDARD SPECTRUM
MODIFIED SPECTRUM
NUMBER OF ROWS
1000
800
600
400
200
100
80
60
40
20
0
.002
.004
.006
.008
.010
.012
.014
.016
d* = FLOAT DIAMETER / λo

TABLE I

NUMBERS OF ROWS REQUIRED FOR C_t = 0.5, STANDARD

AND "DECAYED STANDARD" SPECTRA, d^* = 0.01

SPECTRUM	H_s / λ_o	NUMBERS OF ROWS C_t = 0.5
Standard	0.0237	78
Decayed standard	0.00984	84

7. NUMBERS OF ROWS FOR OTHER VALUES OF C_t:

Figure 5, which depicts performance for $C_t = 0.5$, can be used to approximate the number of rows required to achieve other height transmission ratios. Numerical modeling has shown that

$$(C_t)^{1/n} = \text{constant} \tag{5}$$

where n = number of rows corresponding to that value of C_t for a given spectrum and d*.

Defining,

$$\beta = (0.5)^{1/n_{0.5}} \tag{6}$$

where $n_{0.5}$ = number of rows for $C_t = 0.5$

then, a value for n can be determined from

$$C_t = \beta^n \tag{7}$$

for any value of C_t.

8. MOORING LOADS:

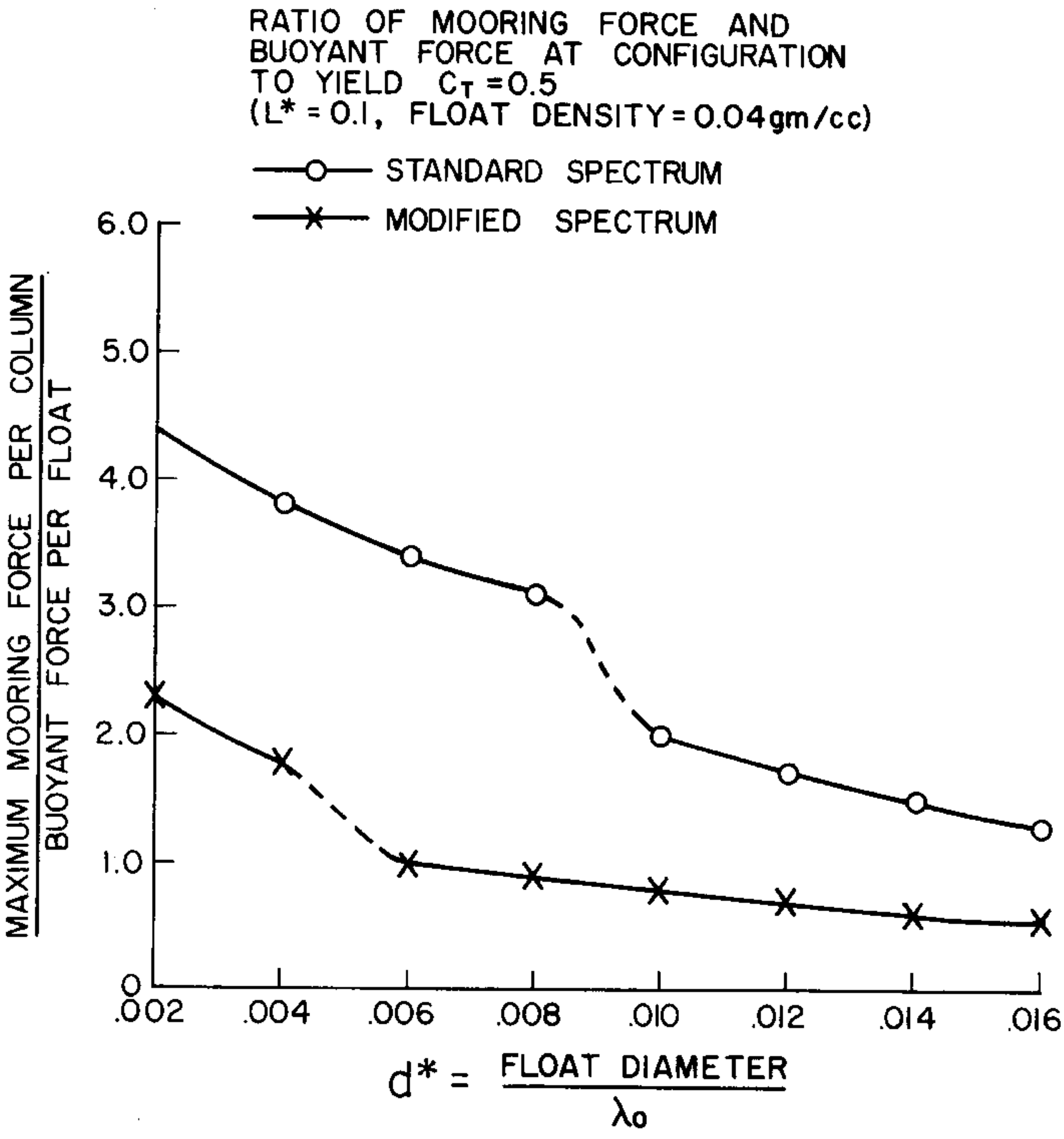
The method for estimating the maximum mooring load is described in Seymour (1975). This procedure establishes a value for the maximum horizontal force on the ballast contributed by a single column of floats. Rows of floats are defined as extending in the length direction and columns in the beam direction (See Figure 1.) For purposes of this report, the non-dimensionalized distance between columns is fixed at 2d*, so that the maximum force per unit breakwater length can be calculated readily. Seymour (1975) shows that the mooring force can be non-dimensionalized approximately by dividing by the maximum buoyant force per float. Figure 6 shows curves of the ratio of maximum mooring force per column to the buoyant force per float for various values of d* for both standard and modified spectra. The inflections in these curves are caused when the beam dimension reaches an optimum length for that spectrum. In general, for a given float diameter, the maximum mooring loads will increase with decreased number of rows and decrease with increased rows.

It should be noted that in long breakwaters ($>2\ \lambda_o$), the maximum mooring load will not occur simultaneously over the entire length of the structure because of the short-crestedness of ocean waves.

9. OFF DESIGN PERFORMANCE:

If a breakwater configuration is selected for a given design condition, it is of interest to know what performance could be expected from that same configuration under different wave conditions. Figure 7 shows the transmission coefficients that are predicted for various values of d* (calculated from the design wavelength) if standard spectra of differing wavelengths are incident on the breakwater. The breakwater, in each case, has the proper number of rows to yield $C_t = 0.5$ with the design spectrum. Curve A has a wavelength equal to

Figure 6


RATIO OF MOORING FORCE AND BUOYANT FORCE AT CONFIGURATION TO YIELD $C_T = 0.5$
($L^* = 0.1$, FLOAT DENSITY = 0.04 gm/cc)
STANDARD SPECTRUM
MODIFIED SPECTRUM
MAXIMUM MOORING FORCE PER COLUMN / BUOYANT FORCE PER FLOAT
6.0
5.0
4.0
3.0
2.0
1.0
0
.002
.004
.006
.008
.010
.012
.014
.016
$d^* = \frac{\text{FLOAT DIAMETER}}{\lambda_0}$

$1.56\ \lambda_o$, $\lambda_\beta = 0.562\ \lambda_o$, and $\lambda_c = 0.25\ \lambda_o$. Thus Curve A has a peak period of 1.25 times the design period, while Curves B and C are 0.75 and 0.50 times, respectively. Figure 8 shows the same information for a modified spectrum. In this case, the wavelengths of both spectral peaks are modified by the ratios indicated above.

Figures 7 and 8 show that the change in C_t is nearly independent of diameter and is roughly proportional to the change in the peak wavelength.

10. MOORING LOADS UNDER GREATER THAN DESIGN CONDITIONS:

The maximum mooring load is increased under conditions where the design wave spectrum is exceeded.

For example:the Curve A condition of the previous section, where $\lambda_A = 1.56\ \lambda_o$, such that the energy in the 'A' spectrum is 2.44 times that of the design spectrum. Table II shows the ratio of the maximum mooring load per column under the overdesign condition to that under the design condition for various values of d* calculated from the design wavelength. Values are shown for both the standard and the modified spectra.

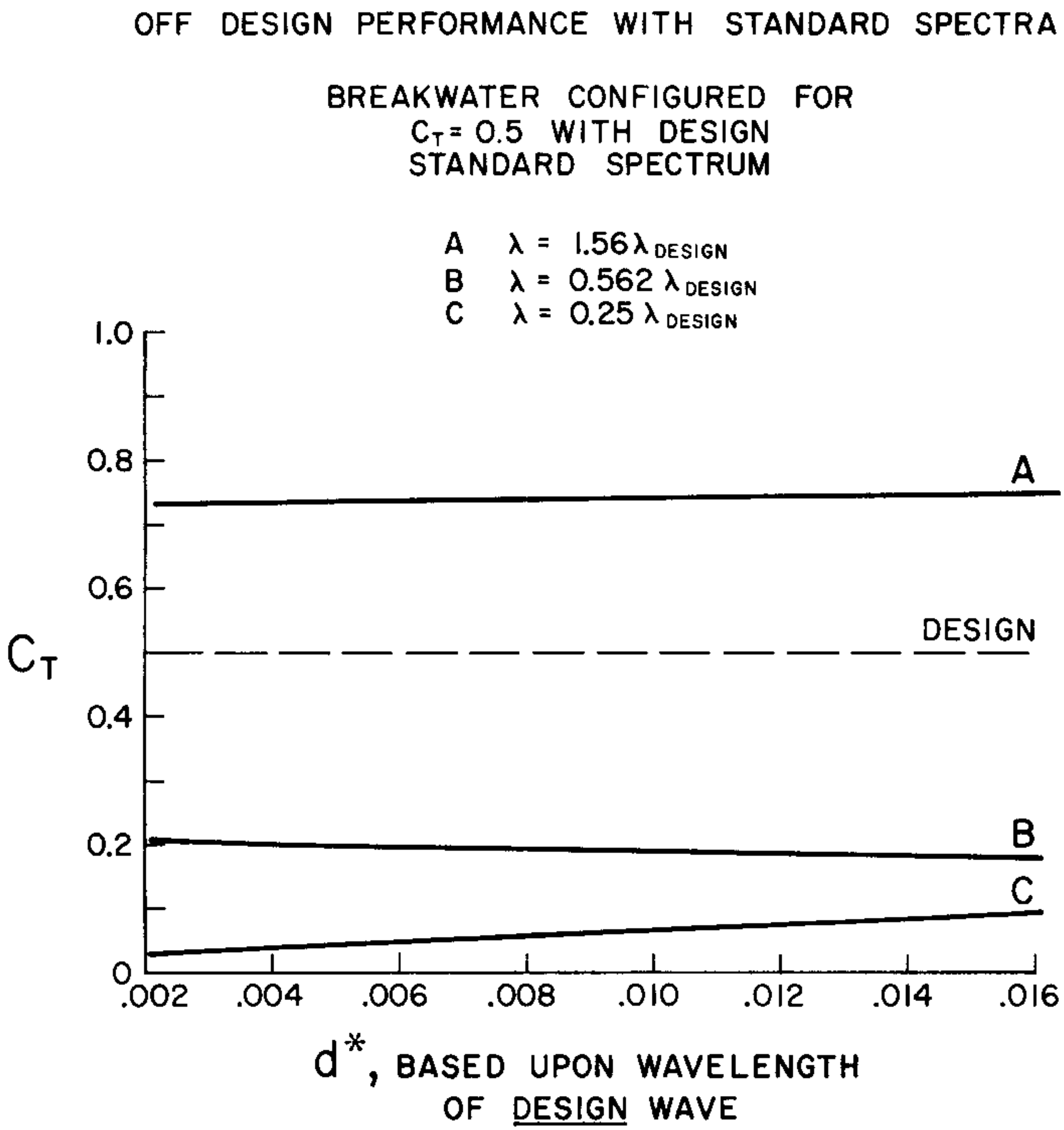

OFF DESIGN PERFORMANCE WITH STANDARD SPECTRA
BREAKWATER CONFIGURED FOR
C_T = 0.5 WITH DESIGN
STANDARD SPECTRUM
A λ = 1.56 λ DESIGN
B λ = 0.562 λ DESIGN
C λ = 0.25 λ DESIGN
1.0
0.8
0.6
0.4
0.2
0
C_T
A
DESIGN
B
C
.002
.004
.006
.008
.010
.012
.014
.016
d*, BASED UPON WAVELENGTH
OF DESIGN WAVE

Figure 8

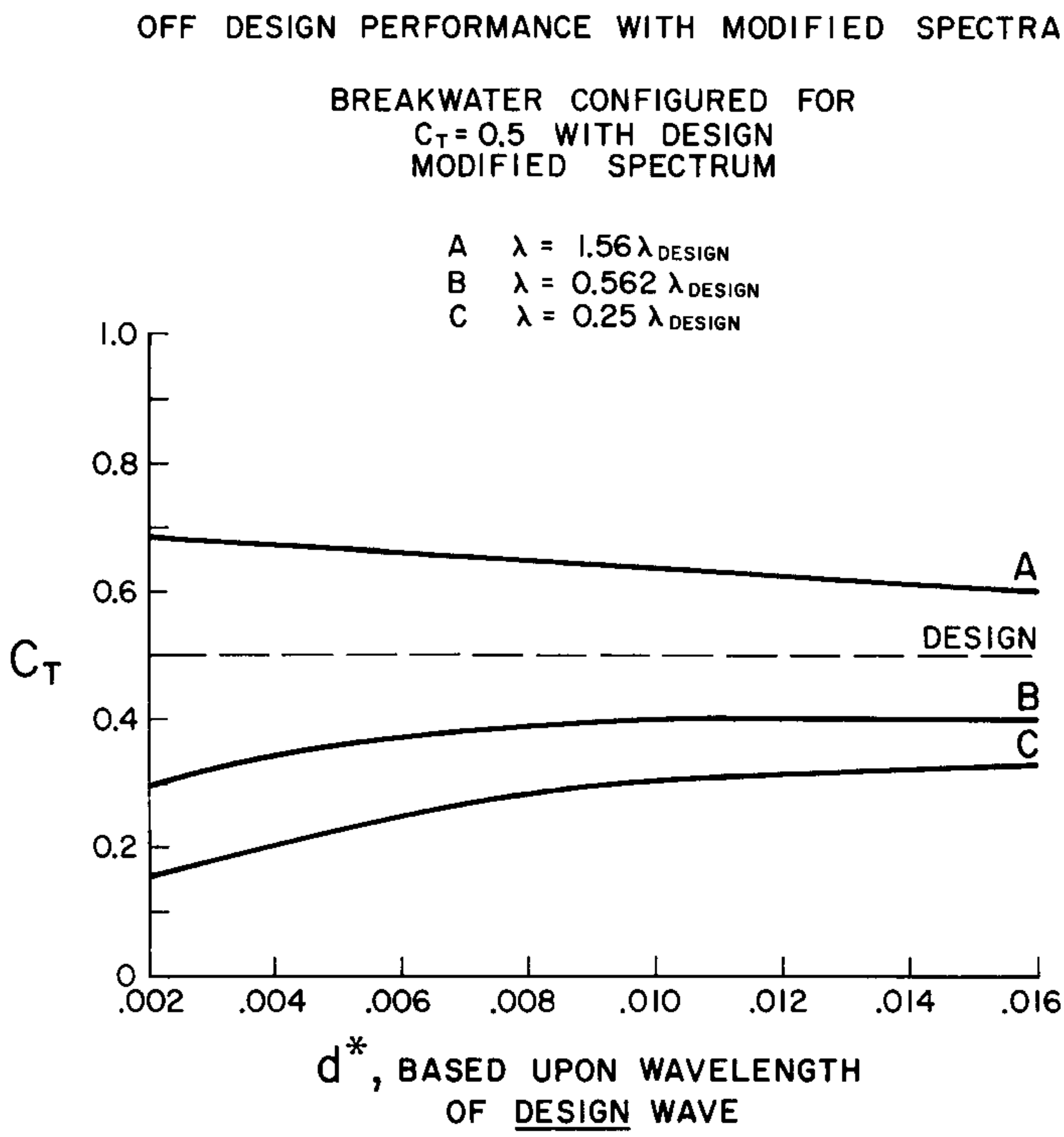

OFF DESIGN PERFORMANCE WITH MODIFIED SPECTRA
BREAKWATER CONFIGURED FOR
$C_T = 0.5$ WITH DESIGN
MODIFIED SPECTRUM
A $\lambda = 1.56\,\lambda_{DESIGN}$
B $\lambda = 0.562\,\lambda_{DESIGN}$
C $\lambda = 0.25\,\lambda_{DESIGN}$
1.0
0.8
0.6
0.4
0.2
0
C_T
A
DESIGN
B
C
.002
.004
.006
.008
.010
.012
.014
.016
d^*, BASED UPON WAVELENGTH
OF DESIGN WAVE

TABLE II

RATIO OF MAXIMUM MOORING LOADS FROM CURVE A
AND DESIGN SPECTRA

$$\frac{\text{MAXIMUM MOORING LOAD (Curve A Spectrum)}}{\text{MAXIMUM MOORING LOAD (Design Spectrum)}}$$

d*	STANDARD	MODIFIED
0.002	2.70	2.40
0.004	2.25	1.92
0.006	1.97	2.04
0.008	1.83	1.98
0.010	1.75	1.87
0.012	1.70	1.76
0.014	1.70	1.70
0.016	1.71	1.66

11. CONCLUSIONS:

A method has been presented to allow the preliminary design of a tethered float breakwater to provide any required level of wave attenuation in deep water for a given incident wave spectrum of a particular form. Broad spectra are shown to require significantly fewer rows than peaky spectra.

From the curves, tables and formulas presented, the following data can be evolved:

1. Effects of selected float diameter on breakwater size.
2. Number of rows for a given diameter and height reduction requirement.
3. Maximum mooring force per unit length.
4. Tether length.
5. Breakwater beam.
6. Estimates of performance and maximum mooring force under conditions exceeding the design spectrum.

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We also wish to acknowledge our graditude for the funding support and information provided by the California Department of Navigation and Ocean Development.